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(71) Applicant: ORMCO CORPORATION [US/US]; 1717 West Collins Avenue, Orange, CA 92867 (US).

(72) Inventors: TAYLOR, Tim, L.; 1301 Santanella Terrace, Corono Del Mar, CA 92625 (US). VASQUEZ, Ramon, G.; 72 Havenwood Drive, Irvine, CA 92614 (US). SINGLETON, David, C.; 7647 Boeing Avenue, Los Angeles, CA 90045 (US). NIGHTINGALE, John, T.; 7647 Boeing Avenue, Los Angeles, CA 90045 (US).

(74) Agents: ROONEY, Kevin, G. et al.; Wood, Herron & Evans, L.L.P., 2700 Carew Tower, Cincinnati, OH 45202 (US).

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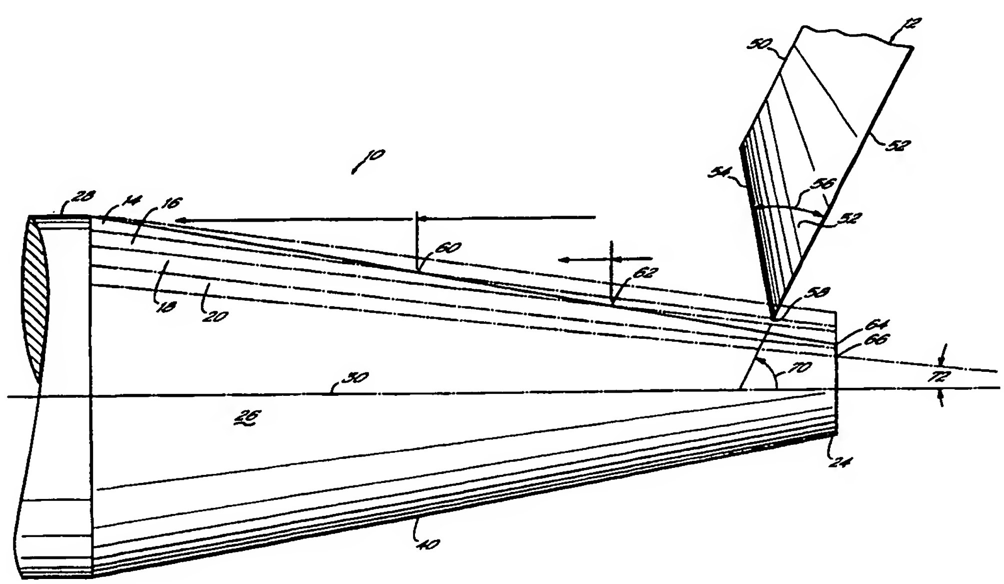
(54) Title: MULTI–PASS GRINDING METHOD



(57) Abstract

A multi–pass grinding method for fabricating an endodontic instrument. A tapered rod (10) is sucessively advanced past a rotating grinding wheel (12) to remove layers (14, 16, 18, 20) of material from the rod (10) until attaining a desired flute depth. The method is characterized by relatively shallow cutting depths, relatively high feed rates and low grinding wheel wear. The method reduces the process time and operator supervision required for fabricating nickel–titanium endodontic instruments. A further process is disclosed for automatically compensating for wear on the grinding wheel (12) so that periodic recalibration of the grinding wheel (12) may be eliminated or reduced.

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MULTI-PASS GRINDING METHOD

FIELD OF THE INVENTION

This invention generally relates to an improved method for fabricating endodontic files and reamers and, more particularly, an improved multi-pass grinding method for forming flutes and associated cutting edges in a tapered rod of nickel titanium alloy material.

BACKGROUND OF THE INVENTION

As part of a conventional root canal procedure, decayed material is removed from the root canal and the canals themselves are reshaped before a filler material is inserted into the canal. The crown of the tooth is removed to provide access to the root canal. Specialized endodontic instruments, such as files and reamers, are used during the root canal therapy to clean out and shape the root canal.

These instruments are typically very flexible files or reamers that are manually rotated and/or reciprocated by the practitioner in the root canal. The practitioner begins with very small files and proceeds with larger and larger files until the canal is properly shaped and cleaned. After this

stage of the root canal therapy is complete, the tooth is typically filled with an inert filling material, such as gutta percha, followed by cement. A crown may then be fitted to the tooth.

In the past, such endodontic instruments were made from tapered rods of stainless steel which were fluted along a working portion thereof to form helical flutes each flanked by one or more cutting edges. The flutes on the instruments are generally formed in one of two ways. A first method involves twisting a rod of a particular cross section, such as triangular or rectangular, so that the edges of the rod form spirals along the length of the rod. These spiraling edges act as the cutting edges of the instrument. Another method is to pass the tapered rod under a grinding wheel and simultaneously rotate and translate the rod to form one or more continuous flutes along the length of the rod. The rod may be indexed and rotated and the process repeated to form additional flutes spaced apart from one another by a predetermined angle, as desired.

The present invention relates to an improved grinding method particularly suited for forming flutes in tapered rods comprising nickel-titanium (Nitinol™) and/or similar alloys. These alloys have superior flexing ability and resistance to fracture when compared to conventional stainless steel alloys and, therefore, have found favorable application in the endodontic field and, particularly, endodontic files and reamers. See, for example, "An Initial Investigation of the Bending and the Torsional Properties of Nitinol Root Canal Files," *Journal of Endodontics*, Vol. 14, No. 7, at 346-51 (July 1988). Such instruments can more easily follow the

curved and/or convoluted contours of a tooth's root canal system, and are less likely than stainless steel to break when placed under stress. These advantages allow faster and more efficient root canal procedures with less likelihood of damage to the wall of the root canal than with stainless steel instruments.

The peculiar material properties and superelastic nature of nickel-titanium alloys make it a particularly difficult material to machine using conventional grinding techniques. For example, U.S. Pat. No. 5,464,362 to Heath et al. discusses some of the difficulties encountered in forming a fluted endodontic instrument from nickel-titanium alloys using conventional grinding techniques. To alleviate some of these difficulties, Heath discloses a grinding method which uses a reduced feed rate of about 3-8 inches per minute and a reduced grinding wheel speed of not more than 3000 surface feet per minute to achieve instruments of acceptable quality.

However, the method of Heath is slow and inefficient and requires shutting down and redressing the grinding wheel at relatively frequent intervals to remove build up of nickel-titanium material on the wheel and/or to reshape or recalibrate the wheel. These operations are slow and labor intensive and, therefore, undesirable for high-production manufacturing of nickel-titanium endodontic instruments.

SUMMARY OF THE INVENTION

The present invention is directed to a high-speed, multi-pass grinding method for fabricating files and reamers and/or other instruments from tapered rods of nickel-titanium or other material. The preferred

method produces instruments of acceptable quality and clinical efficacy, while reducing manufacturing time, wheel wear, and frequency of required wheel redressing. Utilizing the multi-pass grinding method of the present invention, high-quality nickel-titanium endodontic instruments can be fabricated more quickly, with improved manufacturing tolerances and reduced operator supervision and maintenance. The invention also provides, in one embodiment, a method and apparatus for automated recalibrating of the grinding wheel as it wears in order to maintain desired manufacturing tolerances over long production runs and without operator intervention.

In one embodiment, the present invention provides an improved grinding method in which flutes, and associated cutting edges, are formed in a tapered rod of nickel-titanium alloy by a multi-pass grinding operation. The tapered rod is subjected to successive passes of a grinding wheel which removes more and more material on each pass, until the final desired flutes are formed. Because the depth of the flutes typically varies along the length of a tapered instrument, a multi-pass grinding operation allows the feed rate of each pass to be optimized according to the depth of cut for the particular grinding pass. This is a significant advantage over conventional grinding techniques which utilize only single pass, constant feed-rate grinding wheel. This is because in a single pass system, the feed rate must be slow enough to effectively remove the material in the deepest portions of the flute, even though a higher feed rate could be used to remove material from the shallower portions of the flute. The present

invention overcomes this limitation by utilizing multi-pass grinding and variable feed-rates.

Another advantage of the multi-pass grinding method of the present invention is that the depth of cut and the feed rate for each grinding pass can be optimized to impart minimal wear to the grinding wheel. In contrast, a single pass grinding method generates wear on the grinding wheel at a relatively fast rate because the depth of cut is always at a maximum (at least over a portion of the instrument) in order to remove all of the material in one pass. As the edge of the grinding wheel wears under these conditions, it becomes wider or flatter and, thus, the flutes become wider and more shallow. Conventionally, when this occurs an operator must reform or "redress" the edge of the grinding wheel and recalibrate it to maintain manufacturing tolerances. The method of the present invention, however, adjusts the depth of cut for each pass in order to minimize wheel wear, while maintaining high-speed production. Accordingly, the method of the present invention significantly reduces the amount of down-time and skilled labor required to monitor and maintain manufacturing operations.

In another embodiment, the present invention provides a method and apparatus for automated recalibrating of the grinding wheel as it wears. Conventional grinding operations require periodic recalibration and adjustment of the grinding wheel in order to compensate for gradual wearing away of the grinding wheel and the resulting reduction in wheel diameter. This requires temporary shut-down and interruption of the manufacturing process and increases monitoring and supervision costs of

the overall manufacturing process. In accordance with one method of the present invention, however, automatic sensing and/or adjustment of the position of the grinding wheel relative to the work piece (ie. tapered rod) compensates for gradual wearing of the grinding wheel. This reduces the amount of manufacturing time and operator supervision required, which is especially advantageous for long production runs.

In accordance with another embodiment, the present invention provides an adjustable head that holds the grinding wheel, enabling the angle between the axis of the grinding wheel and the axis of the rod to vary. This allows further correction for wear on the grinding wheel and the ability to independently vary the rake angle, depth and width of the flutes as the grinding wheel moves along the instrument.

These and other features and advantages of the present invention will be readily apparent to those skilled in the art from the following detailed description of the preferred embodiment with reference to the accompanying drawings, the invention not being limited, however, to any particular preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is an elevational view of a rod and a grinding wheel, schematically showing the paths and different starting points of the grinding wheel on consecutive passes over the rod;

Figure 1B is a view similar to Figure 1A, but illustrating the grinding wheel having a common starting point for each pass;

Figure 2A is a front view of one type of file being ground by a wheel in accordance with the invention;

Figure 2B is a top view of the file and grinding wheel shown in Figure 2A;

Figure 3A-1 shows an enlarged view of an unworn grinding wheel cutting edge;

Figure 3A schematically illustrates a cross section of rod formed with the grinding wheel of Figure 3A-1;

Figure 3B-1 shows an enlarged view of a worn grinding wheel cutting edge;

Figure 3B schematically illustrates a cross section of rod formed with the grinding wheel of Fig. 3B-1;

Figure 4 is an elevational view of a file ground in accordance with the invention;

Figure 4A shows a transverse cross section of the distal end of the ground rod shown in Fig. 4; and

Figure 4B shows a transverse cross section of the proximal end of the ground rod shown in Fig. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figures 1A, 2A and 2B illustrate a multi-pass grinding method in accordance with present invention. A rod 10 is passed over by a grinding wheel 12 to remove a first layer 14, a second layer 16, a third layer 18, and a fourth layer 20, as shown in Figure 1. The grinding wheel

is shown on its second pass where it will remove the second layer 16, forming a flute.

The rod 10 generally comprises a shank 22, a distal end 24, and a working portion 26. The working portion 26 extends from a proximal end 28 adjacent the base of the shank 22 to the distal end 24. The rod 10 may be rotated along a longitudinal axis 30. The shank 22 may also contain calibrated depth markings 32, a handle 34, knurling or grooves for a chuck (not shown) to accommodate either manual manipulation or use with a motorized handpiece, as desired.

The rod 10 may be of any cross sectional shape, but a circular cross section is preferred. The rod 10 may or may not be tapered, but a taper 40 along the working portion 26, as shown in Figure 1A in exaggerated form, is preferred. The rod 10 may be composed of titanium alloy or stainless steel. Such titanium alloys typically have a titanium content of at least 40%. Nickel-titanium alloys, which are preferred for endodontic work, typically consist of about at least 40% titanium and at least 50% nickel. In one preferred embodiment, the alloy consists of 44% titanium and 56% nickel and no appreciable amount of other materials which could adversely effect the purity required for endodontic instruments. The dimensions of various rods formed into endodontic instruments may be conventional.

The grinding wheel 12 generally comprises a first side 50, a second side 52, and a bevelled side 54. The second side 52 and the bevelled side 54 form a corner 56 with an included angle of about 32° in

one preferred embodiment. A cutting edge 58 is formed at the tip of the corner 56. The second side 52 of the grinding wheel 12 and longitudinal axis 30 of the rod 10 form a head angle 70. The grit size on the grinding wheel 12 may range from about 200 to about 800, more preferably about 250 to about 550, and most preferably about 400. The grinding wheel surface may be composed of a Cubic Boron Nitride (CBN) material, supplied and manufactured by Norton Superabrasives. A grinding wheel 12 composed of diamond ore has also shown to be satisfactory. The speed of the grinding wheel 12 may range from about 2000 rpm to about 10000 rpm and more preferably from about 5000 rpm to about 8500 rpm. Currently, the preferred speed is 5730 rpm for a six inch wheel. High-speed grinding has been achieved with favorable results using a Rollomatic 600x 6-axis machine. A Rollomatic 24F3 3-axis machine has also shown satisfactory results, but cannot be used with head angle variation, discussed in more detail below.

In one multi-pass grinding method in accordance with the present invention, the grinding wheel 12 first contacts the rod 10 at a first pass entrance point 60, somewhere between the distal end 24 and the proximal end 28. The path of the cutting edge 58 of the grinding wheel 12 forms a cutting angle 72 with the longitudinal axis 30 of the rod 10. The cutting angle 72 is preferably greater than or equal to about 0°, to provide a neutral or positive rake angle cutting edge, although the method is not specific to a particular instrument geometry. The depth of the first pass or "cut" 14 is preferably less than a total maximum flute depth, which includes

the first cut 14, the second cut 16, the third cut 18, and the fourth cut 20. Although the depth of any of the cuts is not critical, the depth of the final cut or grinding pass (the fourth cut 20 in Figure 1A) is preferably about 5 microns to 30 microns deep, and more preferably about 10 microns deep, to provide a fine surface finish quality of the flutes and associated cutting edges. The depth of the other cuts may range from just greater than a few microns to a depth of about 100 microns or more, with about 40 microns per cut being most satisfactory.

Figure 1A depicts a multi-pass grinding method using four passes. The system may also operate satisfactorily with as few as two passes, and as many as ten or more passes. Most preferably, between about three to five grinding passes should be suitable for most applications. Instruments formed from tapered rods of smaller diameters will generally require less grinding passes than those formed from larger diameter rods. While moving between the distal end 24 and the first pass entrance point 60, the grinding wheel 12 may move at a rapid feed rate, such as 1800 mm/min. (approx. 72"/min.). Just before contacting the rod 10 at the first pass entrance point 60, the feed rate is preferably slowed to a rate suitable for cutting the material. A grinding feed rate, ranging from about .5"/min. to about 35"/min., and most preferably about 10"/min to about 15"/min. and most preferably about 12"/min. (approx. 300 mm/min.) provides satisfactory results. This grinding feed rate can vary while the grinding wheel 12 is removing material along a pass or from pass to pass, but is

more preferably held constant while the grinding wheel 12 is removing material from the rod 10.

After the first cut 14, the grinding wheel 12 can move at a more rapid feed rate to the second cut entrance point 62 and begin removing the second layer of material 16 at a selected grinding feed rate. The process is repeated until reaching the desired flute depth. A third layer entry point 64 and fourth layer entry point 66 are located at the distal end 24. By employing this multi-pass system, significant savings in time and materials are achieved. This is possible because a single pass system must operate at a grinding feed rate from the distal end 24 to the proximal end 28, and that rate must be relatively slow because the single pass system removes a maximum amount of material at the proximal end 28. A multi-pass grinding method can use faster grinding feed rates because less material is removed per pass. It can also utilize even more rapid feed rates when it is not removing material (or removing only minimal material) from the rod, such as after the initial pass and before the second pass. A four pass system with a grinding feed rate of 12"/min. has approximately a 20% savings in time over a single pass system operating at 3"/min. In addition, when the final layer in a multi-pass system, the fourth layer 20 in Figure 1A, is kept relatively thin, an improved surface finish is obtained.

Referring now to Figure 1B, the multi-pass method of this invention may also be practiced by starting from approximately common starting points at distal end 24. In Figure 1B, like numerals refer to like structure as between Figures 1A and 1B, and numerals having prime marks

(') refer to elements modified according to this alternative principle. The method will be essentially the same as described above, except that layers 14', 16', 18' and 20' will each be ground off with wheel 12 starting at points 60', 62', 64, 66. It will be appreciated that points 60' and 62' have been moved distally from the respective points 60, 62 shown in Figure 1A. These points may vary in depth. Also in accordance with this invention, grinding passes can vary in axial feed rate throughout their entire length. For example, the feed rate at the start of a flute grinding pass may be 10" per minute or greater and the feed rate through the remainder of the grinding pass may become progressively greater, often exceeding 12" per minute but preferably not exceeding 30" per minute.

Referring now to Figures 3A, 3A-1, 3B and 3B-1, the multi-pass system not only saves manufacturing time and costs, but it also reduces the wear on the grinding wheel 12. The unworn cutting edge 58 of grinding wheel 12 produces a flute 100 on the rod 10, as illustrated in Figure 3A. The flute 100 must be maintained within specifications in order to produce instruments of acceptable quality and clinical efficacy. The width "a" of the flute and depth "b" of the flute, among other physical properties, can be measured to gauge the acceptance of the shapes and dimensions of the flutes. Figure 3B-1 depicts a worn cutting edge 58' and a cross section of its corresponding rod 10 and flute 100'. As illustrated, a worn cutting edge 58' will produce a shallower and flatter flute so that a' is greater than a and b' is less than b. Eventually the worn edge 58' will prevent the flutes 100' from meeting specifications. The manufacturing

process will then have to be interrupted so that an operator can reform the cutting edge 58′ and recalibrate the grinding wheel 12 by moving the cutting edge 58′ by a distance "c" in the direction of arrow 59 in Figure 3B-1 so that it will produce a flute 100 of proper dimensions. The multi-pass system lessens the need for this recalibration because the grinding wheel 12 wears more slowly in a multi-pass system as compared to a single pass system.

As just described, the need to stop the manufacturing process for recalibration of the wheel increases process time and the need for operator supervision. Therefore, any increase in the length of time between recalibrations increases the efficiency of the process. This remains the case whether a single pass or multi-pass system is utilized. The present invention, in one embodiment, increases the time between necessary recalibrations significantly by automatically feeding the grinding wheel 12 and its cutting edge 58 toward the rod 10 as edge 58 wears. By tracking the wear of cutting edge 58, it is possible to adjust the location of the cutting edge 58 to account for the wear. By repeatedly readjusting the location of the cutting edge 58 as it wears, the flute 100 is kept within specifications for a much longer period of time. Even after fabricating 50 parts, grinding wheel 12 used in accordance with the invention was still producing flutes 100 well within specifications. The infeeding is accomplished by programming a computer (not shown) that will move the grinding wheel 12 along an axis parallel to its second side 52, so that the head angle 70 remains constant.

The present invention, in another embodiment, is also capable of adjusting the head angle 70 shown, for example, in Figure 1A. This process is similar to the infeeding process discussed above, except that in this case the head angle 70 is altered to correct for wear on the cutting edge 58, rather than the distance between the axes of the grinding wheel 12 and rod 10. The result is decreased down time because the head angle correction maintains more symmetrical flutes 100 for a longer period of time.

Referring now to Figures 4, 4A and 4B, adjustment of the head angle 70 can also be utilized to improve and control other variables of the flutes 100. As one skilled in the art is aware, material can be removed from the rod 10 to produce one or a plurality of flutes 100. These flutes 100 are helical, and form leading edges 102 that cut away decayed material as the rods 10 are maneuvered in the root canal. The flutes 100 also form trailing edges 104. As Figures 4A and 4B illustrate, the leading edges 102 form rake angles which may be 0°, positive, or negative, as desired. As one can see from these two figures, the cross section at distal end 24 has a rake angle of approximately 0° and the rake angle at proximal end 28 is on the order of about 20 degrees. The varying rake angle between distal end 24 and proximal end 28 is caused by the fixed head angle employed in present systems. The fixed head angle produces different rake angles depending on the depth of cut. By varying the head angle, the rake angle can be kept constant if desired, or varied at a controlled rate. The same is true for the web thickness. The head angle can be adjusted with a

programmable computer or other expedients, as will be readily apparent to those skilled in the art.

Although the present invention has been disclosed in the context of certain preferred embodiments, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiments to other equivalent and obvious alternative embodiments. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiments herein, but shall be defined only by a fair reading of the claims which follow, including the full range of equivalents to which they may be entitled by law.

WHAT IS CLAIMED IS

1. A multi-pass grinding method for fabricating an endodontic instrument used during root canal therapy, the method comprising:

axially moving a metallic rod relative to and against a rotating grinding wheel to grind off an amount of metallic material from the outer surface of said rod along a path and during a first pass, and

axially moving said metallic rod relative to and against said rotating grinding wheel during at least one additional pass over at least a portion of said path to grind off a further amount of metallic material from the outer surface of said rod until reaching a desired depth.

2. The method of Claim 1 wherein the metallic material includes at least about 40% titanium.

3. The method of Claim 1 wherein the number of passes made by the grinding wheel is between 3 and 10.

4. The method of Claim 1 wherein the rod is moved relative to the grinding wheel during each pass at an axial feed rate of between about 10 and 30 inches per minute.

5. The method of Claim 1 wherein the amount of material removed in each pass is between about 10 microns and 100 microns.

6. The method of Claim 1 wherein the amount of material removed in each pass is about 40 microns.

7. The method of Claim 1 wherein the speed of the grinding wheel is between about 5000 rpm to about 8500 rpm.

8. The method of claim 1, wherein a flute of said desired depth and with a spiral cutting edge is formed along said path.

9. The method of claim 1, wherein each pass is started from approximated the same starting point along the length of said rod.

10. The method of claim 1, wherein said first pass and said additional pass are started from different points along the length of said rod.

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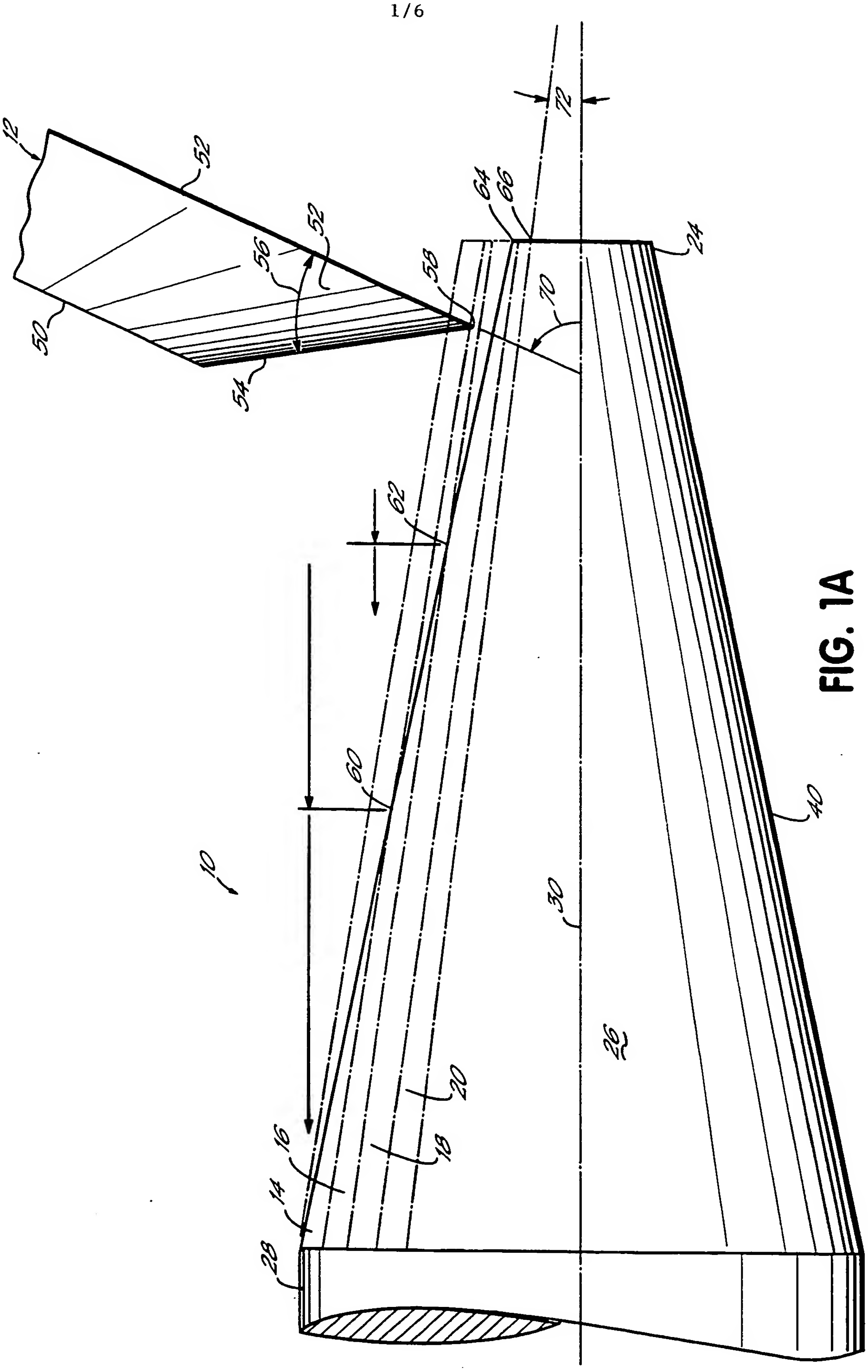

FIG. 1A

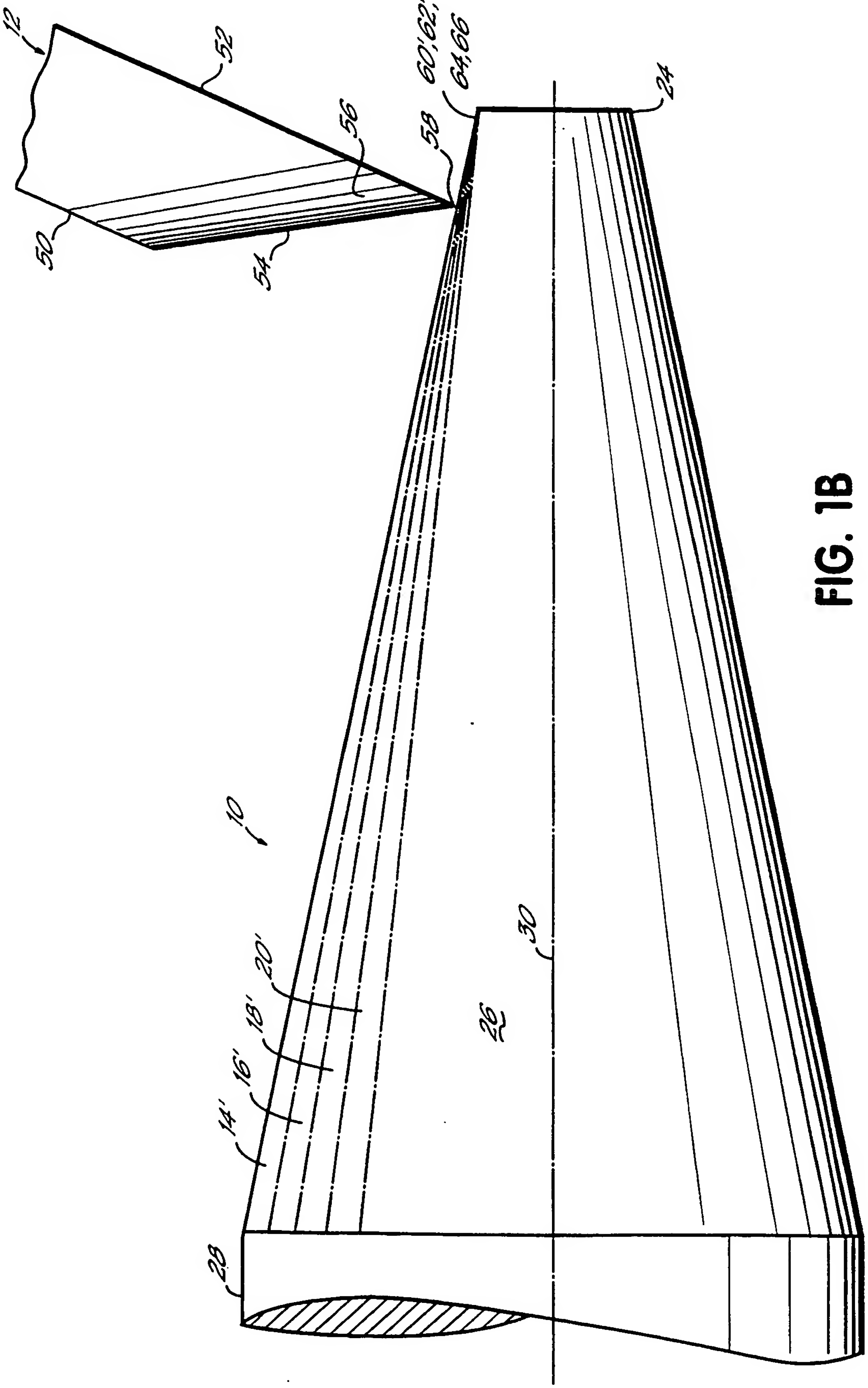

FIG. 1B

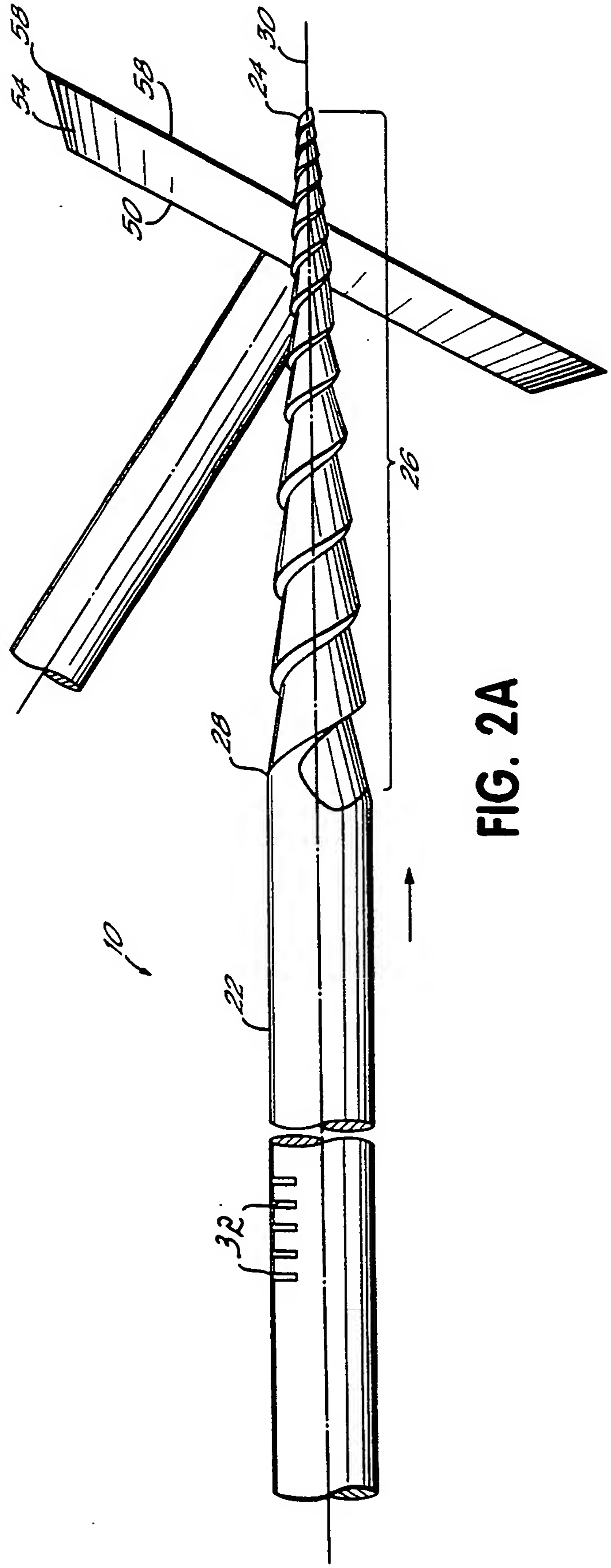

FIG. 2A

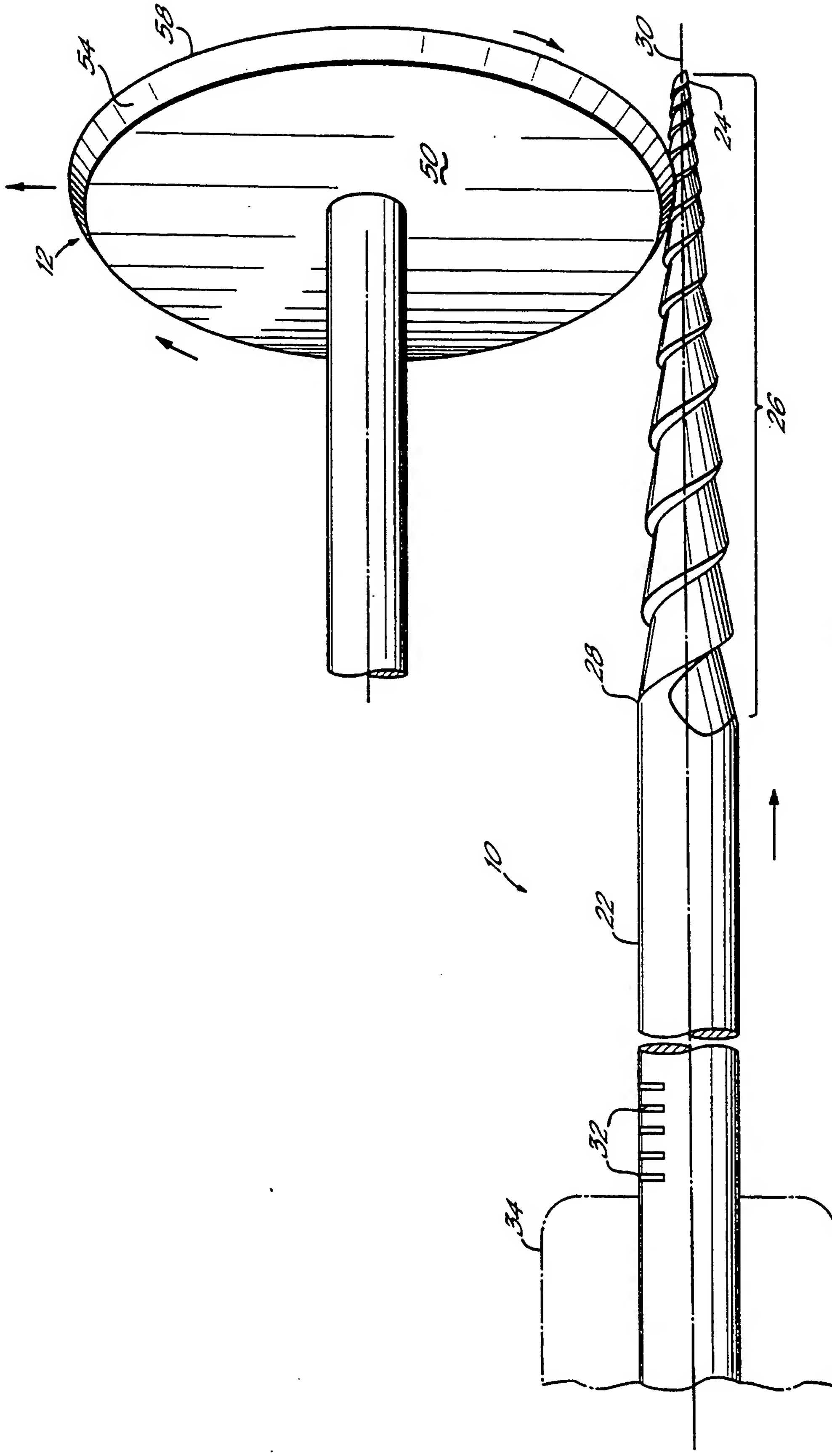

FIG. 2B

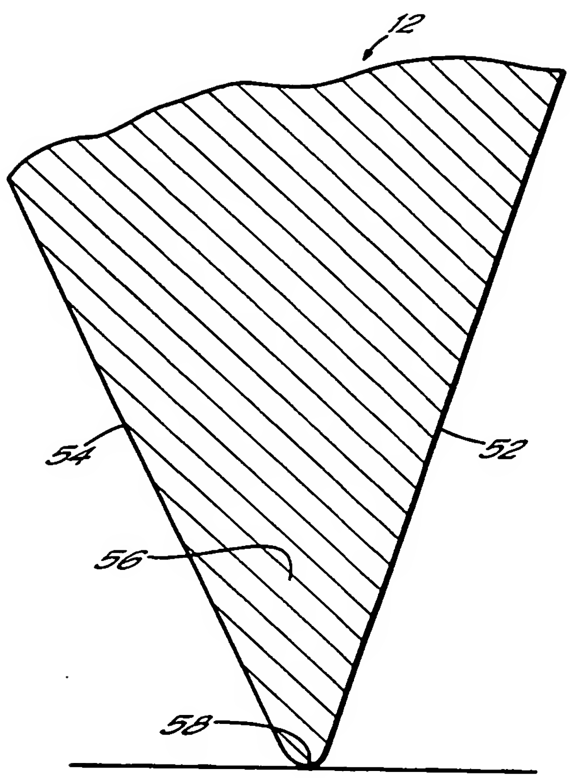

FIG. 3A-1

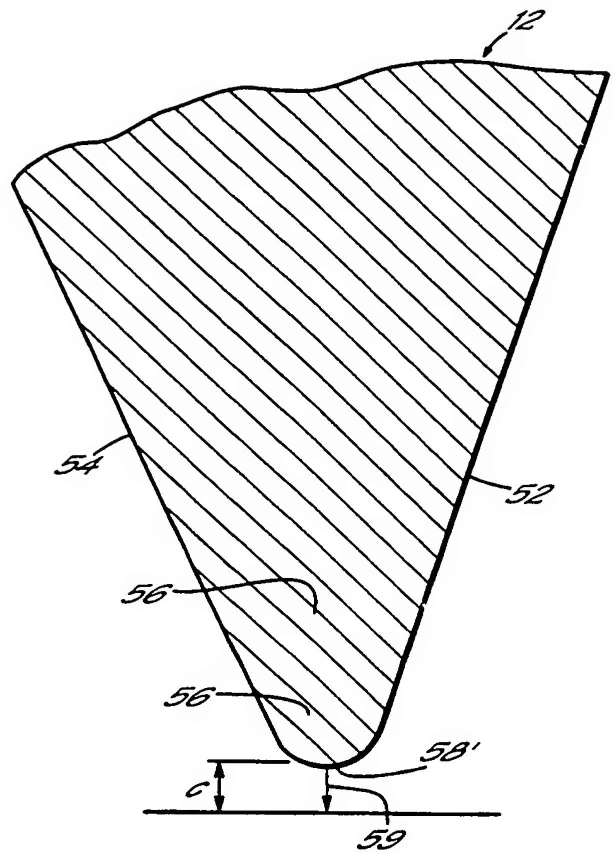

FIG. 3B-1

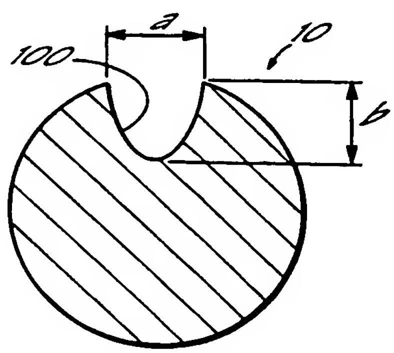

FIG. 3A

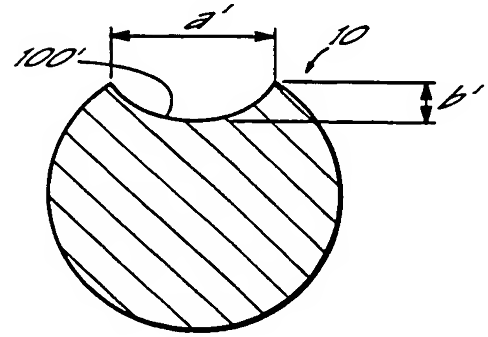

FIG. 3B

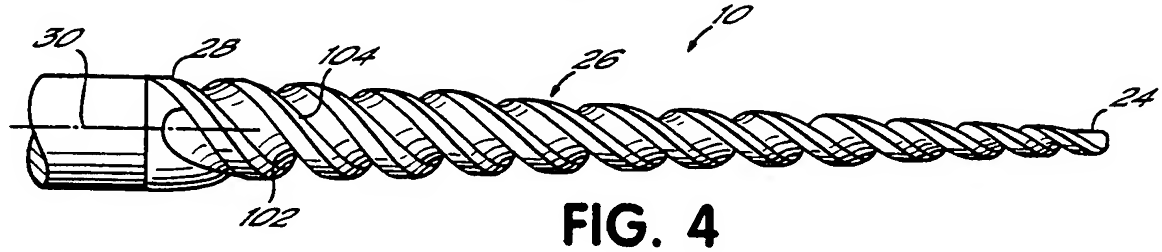

FIG. 4

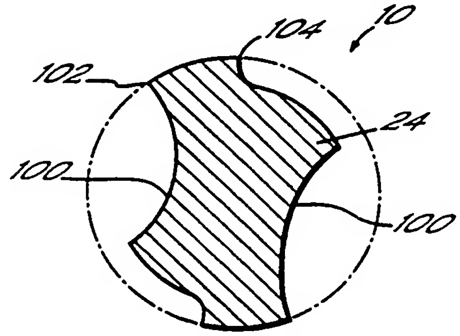

FIG. 4A

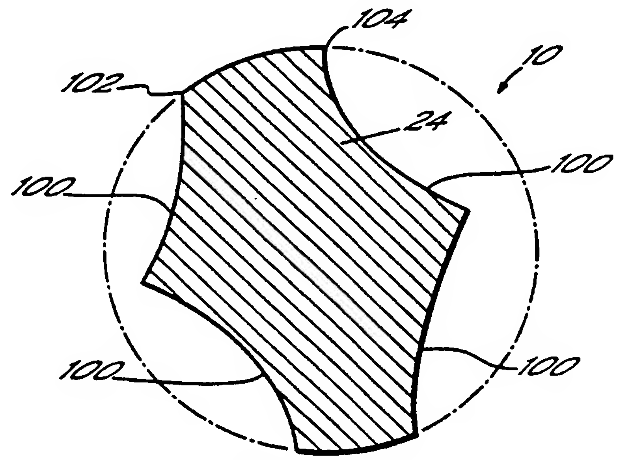

FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/04106

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B24B 19/04
US CL :451/48; 433/102, 224
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 451/28, 48; 433/102, 224, 225, 165

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,762,541 A (HEATH et al.) 09 June 1998, See Entire Document.	1-10
A	US 5,527,205 A (HEATH et al.) 18 June 1996, See Entire Document.	1-10
A	US 5,655,950 A (HEATH et al.) 12 August 1997, See Entire Document.	1-10
A	US 5,762,497 A (HEATH) 09 June 1998, See Entire Document.	1-10
A	US 5,628,674 A (HEATH et al.) 13 May 1997, See Entire Document.	1-10
A	US 5,464,362 A (HEATH et al.) 07 November 1995, See Entire Document.	1-10

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search 20 MAY 1999	Date of mailing of the international search report 01 JUN 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer DAVE SCHERBEL Sheila Veney Paralegal Specialist Technology Center 3700 Telephone No. (703) 308-1272

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,807,106 A (HEATH) 15 September 1998, See Entire Document.	1-10
A	US 5,735,689 A (McSPADDEN) 07 April 1998, See Entire Document.	1-10
A	US 5,902,106 A (McSPADDEN) 11 MAy 1999, See Entire Document.	1-10
A	US 5,882,198 A (TAYLOR et al.) 16 May 1999, See Entire Document.	1-10